4 MIX DESIGN

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4 CHAPTER FOUR
MIX DESIGN

In Hot Mix Asphalt, binder and aggregate are blended together in precise proportions. The relative proportions of these materials determines the physical properties of the HMA and ultimately how the HMA will perform as a finished pavement. The design method for determining the suitable proportions of binder and aggregate in the HMA is the Superpave Method.

MIX CHARACTERISTICS AND BEHAVIOR

When a sample of HMA is prepared in the laboratory, it can be analyzed to determine its probable performance in a pavement structure. The analysis focuses on five characteristics of the HMA and the influence those characteristics are likely to have on HMA behavior. The five characteristics are:

1) Mix Density;
2) Air Voids;
3) Voids in the Mineral Aggregate (VMA);
4) Voids Filled with Asphalt (VFA); and
5) Binder Content.

Before mix properties are discussed in detail the technician should understand that paving mix properties are most affected by volume and not weight; however production and testing of HMA is by weight. An example of the difference between weight and volume of HMA is given in Figure 4-1. Much of what will determine long term pavement performance, such as Air Voids, VMA and VFA, are based on volume and not weight.

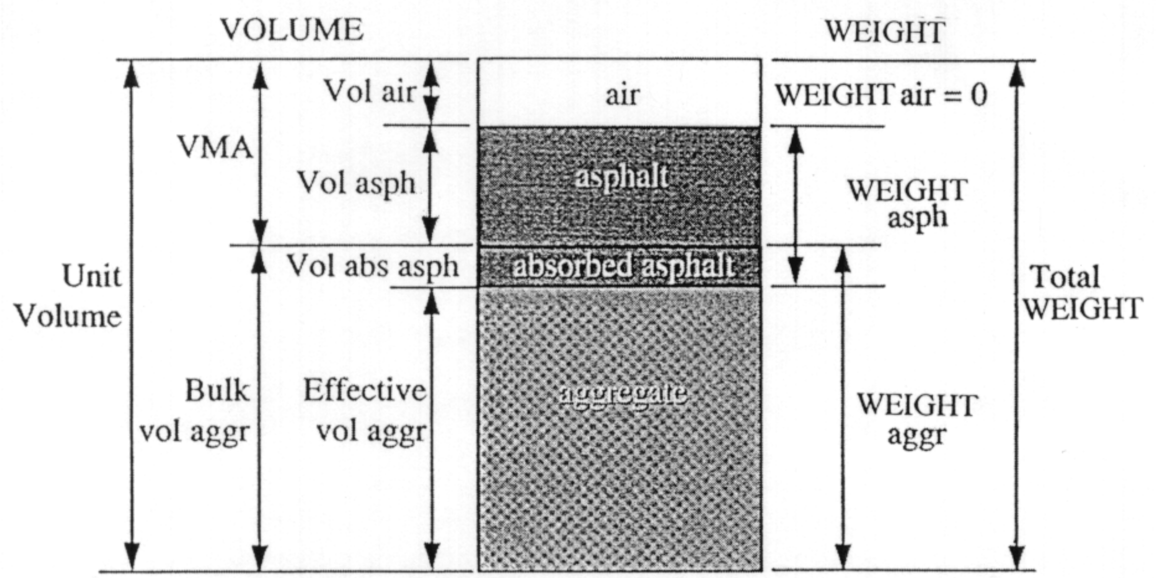

Figure 4-1. Component Diagram of Compacted Sample of Hot Mix Asphalt

Bulk Specific Gravity or Density

The density of the compacted mix is its unit weight (the weight of a specific volume of HMA). Density is important because proper density in the finished product is essential for lasting pavement performance. As we have just discussed above, mix properties need to be measured in volumetric terms as well as weight. Density allows us to convert from units of weight to volume.

In mix design testing and analysis, density of the compacted specimen is usually expressed in pounds per cubic meter (lb/ft^3). The procedure for determining Bulk Specific Gravity and Unit Weight will be discussed later in the section.

Air Voids

Air voids are small air spaces or pockets of air that occur between the coated aggregate particles in the final compacted HMA. A certain percentage of air voids is necessary in all dense-graded mixes to prevent the pavement from flushing, shoving, and rutting.

Air voids can be increased or decreased by lowering or raising the binder content. They can also be increased or decreased by controlling the amount of material passing the No. 200 sieve in the HMA. The more fines added to the HMA generally the lower the air voids. If a plant has a baghouse dust collection system the air voids can be controlled by the amount of fines which are returned to the HMA. Finally, the air voids can be changed by varying the aggregate gradation in the HMA.

The durability of an asphalt pavement is a function of the air void content. Too high an air void content provides passageways through the HMA for the entrance of damaging air and water. Too low an air void content, on the other hand, can lead to flushing, a condition where excess binder squeezes out of the HMA to the surface.

Density and air void content are directly related. The higher the density, the lower the percentage of air voids in the HMA. Specifications require pavement densities that will produce the proper amount of air voids in the pavement

Voids in the Mineral Aggregates

Voids in the mineral aggregate (VMA) are the void spaces that exist between the aggregate particles in the compacted paving HMA, including the space filled with the binder.

VMA represents the space that is available to accommodate the effective volume of binder (i.e., all of the binder except the portion lost by absorption into the aggregate) and the volume of air voids necessary in the HMA. The more VMA in the dry aggregate, the more space is available for the binder. Since a thick binder film on the aggregate particles result in a more durable HMA, specific minimum requirements for VMA are recommended and specified as a function of the aggregate size. Figure 4-2 illustrates VMA.

Minimum VMA values should be adhered to so that a durable binder film thickness can be achieved. Increasing the density of the HMA by changing gradation of the aggregate to a point where minimum VMA values are obtained leads to thin films of binder and a dry looking, low durability HMA. Therefore, economizing in binder content by lowering VMA is actually counter-productive and detrimental to pavement quality. Low VMA mixes are also very sensitive to slight changes in binder. If binder content varies even slightly during production it is possible to fill all of the air voids with binder resulting in a pavement that will flush and rut.

VMA is most affected by the fine aggregate fractions which pass the No. 200 sieve. The reason for this is that these particles tend to be absorbed by the binder film. Because they take up volume, there is a tendency to bulk (extend) the binder resulting in a lower VMA.

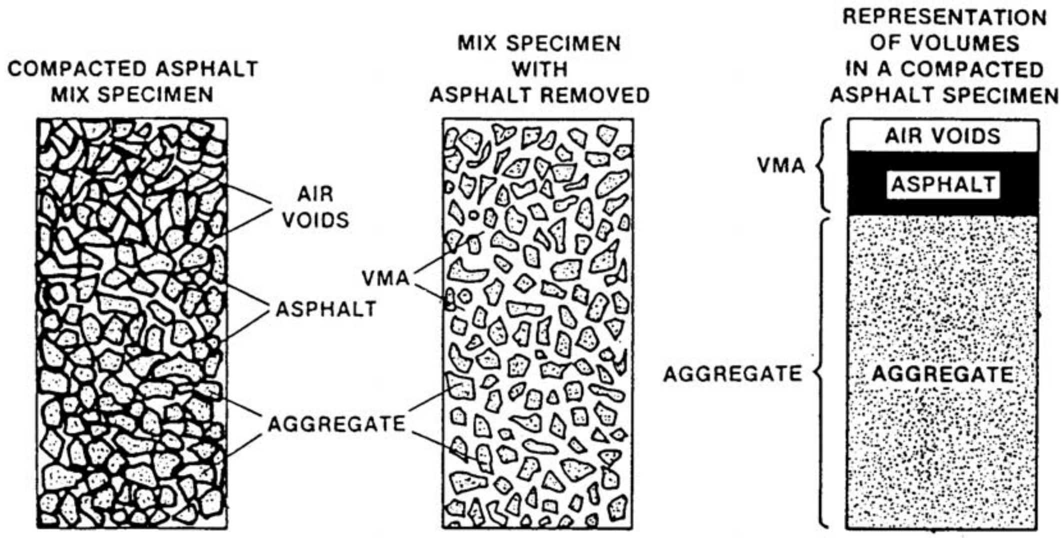

Figure 4-2. Illustration of VMA in a Compacted Specimen
(Note: for simplification the volume of absorbed binder is not shown)

Voids Filled with Asphalt

Voids filled with asphalt (VFA) are the void spaces that exist between the aggregate particles in the compacted paving HMA that are filled with binder. VFA is expressed as a percentage of the VMA that contains binder.

Including the VFA requirement in a mix design helps prevent the design of HMA with marginally acceptable VMA. The main effect of the VFA is to limit maximum levels of VMA and subsequently maximum levels of binder content.

VFA also restricts the allowable air void content for HMA that are near the minimum VMA criteria. HMA designed for lower traffic volumes may not pass the VFA requirement with a relatively high percent air voids in the field even though the air void requirement range is met. The purpose for the VFA is to avoid less durable HMA resulting from thin films of binder on the aggregate particles in light traffic situations.

HMA designed for heavy traffic may not pass the VFA requirement with relatively low percent air voids in the field even though the amount of air voids is within the acceptable range. Because low air void contents can be very critical in terms of permanent deformation, the VFA requirement helps to avoid those mixes that would be susceptible to rutting in heavy traffic situations.

Binder Content

The proportion of binder in the HMA is critical and must be accurately determined in the laboratory and then precisely controlled at the plant. The binder content for a particular HMA is established by the mix design.

The optimum binder content of the HMA is highly dependent on aggregate characteristics such as gradation and absorptiveness. Aggregate gradation is directly related to optimum binder content. The finer the HMA gradation, the larger the total surface area of the aggregate and the greater the amount of binder required to uniformly coat the particles. Conversely, because coarser HMA has less total aggregate surface area, they demand less binder. This is why surface HMA requires more binder than base HMA.

The relationship between aggregate surface area and optimum binder content is most pronounced where very fine aggregate fractions which pass through the No. 200 sieve are involved, such as baghouse fines. Baghouse fines in HMA can act as a binder extender resulting in lower air voids in the HMA and possible flushing. If the binder content is reduced to stop the flushing, the HMA may become dry and brittle. This is because the baghouse fines increase the viscosity of the binder changing its rheological properties. Variations in the amount of fines can cause changes in HMA properties creating a very inconsistent HMA from the standpoint of appearance and performance. When this occurs proper sampling and testing should be done to determine the cause of the variations and to establish a new mix design, if necessry.

The absorptiveness (ability to absorb binder) of the aggregate used in the HMA is critical in determining optimum binder content. Enough binder must be added to the HMA to allow for absorption and also coat the particles with an adequate film. Total binder content and effective binder content are the terms normally used.

Total binder content is the amount of the binder that must be added to the HMA to produce the desired HMA qualities. Effective binder content is the volume of binder not absorbed by the aggregate, i.e., the amount of binder that effectively forms a bonding film on the aggregate surfaces. Effective binder content is calculated based on the aggregate bulk specific gravity (Gsb) and the aggregate effective specific gravity (Gse). The higher the aggrgate absorption, the greater the difference between Gse and Gsb.

Effective binder content should not be confused with the extracted binder content of the HMA. The effective binder content is a theoretical calculated value and the extracted binder content is an actual test value such as obtained for example with an ignition oven or vacuum extractor.

Plant Produced HMA

HMA characteristics are determined in a lab mix design to ensure that the combination of aggregates and binder will meet specification criteria and give long term performance; however, there can be subtle differences between the laboratory designed HMA and what is actually produced by the mixing plant. Plant type and environmental controls all have an effect on the HMA properties and could produce HMA with different characteristics than those designed in the lab. For these reasons, specimens are prepared by the certified technician from plant produced HMA to verify proper density, air voids and VMA from the original laboratory design.

PROPERTIES CONSIDERED IN MIX DESIGN

Good HMA pavements function well because they are designed, produced and placed in such a way as to give them certain desirable properties. There are several properties that contribute to the quality of HMA pavements. They include stability, durability, impermeability, workability, flexibility, and fatigue resistance.

Ensuring that HMA has each of these properties is a major goal of the mix design procedure. Therefore, the technician should be aware what each of the properties measures, how it is evaluated, and what it means in terms of pavement performance.

Stability

Stability of a HMA pavement is its ability to resist shoving and rutting under loads (traffic). A stable pavement maintains its shape and smoothness under repeated loading; an unstable pavement develops ruts (channels), ripples (washboarding or corrugation), raveling and other signs of shifting of the HMA.

Because stability for a pavement depends on the traffic expected to use the pavement, stability can be established only after a thorough traffic analysis. Stability should be high enough to handle traffic adequately, but not higher than traffic conditions required.

The stability of a mix depends on internal friction and cohesion. Internal friction among the aggregate particles (inter-particle friction) is related to aggregate characteristics such as shape and surface texture. Cohesion results from the bonding ability of the binder. A proper degree of both internal friction and cohesion in HMA prevents the aggregate particles from being moved past each other by the forces exerted by traffic.

In general, the more angular the shape of the aggregate particles and the more rough their surface texture, the higher the stability of the HMA will be.

The binding force of a HMA is called cohesion. Cohesion increases with increasing loading (traffic) rate. Cohesion also increases as the viscosity of the binder increases, or as the pavement temperature decreases. Additionally, cohesion will increase with increasing binder content, up to a certain point. Past that point, increasing binder content creates too thick a film on the aggregate particles, resulting in loss of interparticle friction. Insufficient stability in a pavement has many causes and effects. Figure 4-3 lists some of them.

LOW STABILITY

Causes	Effects
Excess binder in HMA	Washboarding, rutting, and flushing or bleeding
Excess medium size sand in HMA	Tenderness during rolling and for a period after construction, and difficulty in compacting
Rounded aggregate, little or no crushed surfaces	Rutting and channeling

Figure 4-3. Causes and Effects of Pavement Instability

Durability

The durability of a HMA pavement is its ability to resist factors such as changes in the binder oxidation, and disintegration of the aggregate. These factors can be the result of weather, traffic, or a combination of the two.

Generally, durability of a HMA can be enhanced by three methods. They are: using maximum binder content, using a sound aggregate, and designing and compacting the HMA for maximum impermeability.

Maximum binder content increases durability because thick binder films do not age and harden as rapidly as thin films. Consequently, the binder retains it original characteristics longer. Also, maximum binder content effectively seals off a greater percentage of interconnected air voids in the pavement, making it difficult for water and air to penetrate. Of course, a certain percentage of air voids must be left in the pavement to allow for expansion of the binder in hot weather.

A dense gradation of sound, tough aggregate contributes to pavement durability in two ways. A dense gradation provides closer contact between aggregate particles. This enhances the impermeability of the HMA. A sound, tough aggregate resists disintegration under traffic.

A lack of sufficient durability in a pavement can have several causes and effects. Figure 4-4 presents a list of some of them.

POOR DURABILITY

Causes	Effects
Low binder content	Dryness or ravelling
High void content through design or lack of compaction	Early hardening of binder followed by cracking or disintegration
Water susceptible (hydrophillic) aggregate in HMA	Films of binder strip from aggregate leaving an abraded, ravelled, or mushy pavement

Figure 4-4.Causes and Effects of Lack of Durability

Impermeability

Impermeability is the resistance of a HMA pavement to the passage of air and water into or through it. This characteristic is related to the void content of the compacted HMA, and much of the discussion on voids in the mix design relates to the impermeability. Even though void content is an indication of the potential for passage of air and water through a pavement, the character of these voids is more important than the number of voids. The size of the voids, whether or not the voids are interconnected, and the access of the voids to the surface of the pavement all determine the degree of impermeability.

Although impermeability is important for the durability of a compacted paving HMA, virtually all HMA used in highway construction is permeable to some degree. This is acceptable as long as it is within specified limits. Causes and effects of poor impermeability values in normal dense-graded HMA pavements are shown in Figure 4-5.

MIX TOO PERMEABLE

Causes	Effects
Low binder content	Thin binder films will cause early aging and ravelling
High void content in design HMA	Water and air can easily enter pavement causing oxidation and disintegration
Inadequate compaction	Will result in high voids in pavement leading to water infiltration and low strength

Figure 4-5. Causes and Effects of Permeability

Workability

Workability describes the ease with which a paving HMA can be placed and compacted. Workability can be improved by changing mix design parameters, aggregate sources, and/or gradation.

Harsh HMA (HMA containing a high percentage of coarse aggregate) has a tendency to segregate during handling and also may be difficult to compact. Through the use of trial mixes in the laboratory, additional fine aggregate and perhaps binder, can be added to a harsh HMA to make it more workable. Care should be taken to ensure that the altered HMA meets all the other design criteria.

Excess fines can also affect workability. Depending on the characteristics of the fines, they can cause the HMA to become tough or gummy, making it difficult to compact.

Workability is especially important where excessive hand placement and raking (luting) around manhole covers, sharp curves, and other obstacles is required. It is important that HMA used in such areas is highly workable.

HMA that can be too easily worked or shoved is referred to as tender HMA. Tender HMA is too unstable to place and compact properly. It often is caused by a shortage of mineral filler, too much medium sized sand, smooth rounded aggregate particles, or excess moisture in the HMA.

Although not normally a major contributor to workability problems, the binder does have some effect on workability. Because the temperature of the HMA affects the viscosity of the binder, too low a temperature will make HMA unworkable, too high a temperature may make it tender. Binder grade may also affect workability, as may the percentage of binder in the HMA.

Figure 4-6 lists some of the causes and effects related to workability of paving mixes.

POOR WORKABILITY

Causes	Effects
Large maximum size particle	Rough surface, difficult to place
Excessive coarse aggregate	May be hard to compact
Too low a HMA temperature	Uncoated aggregate, not durable, rough surface, hard to compact
Too much medium sized sand	HMA shoves under roller, remains tender
Low fines content	Tender HMA, highly permeable
High fines content	HMA may be dry or gummy, hard to handle, not durable

Figure 4-6. Causes and Effects of Workability Problems

Flexibility

Flexibility is the ability of a HMA pavement to adjust to gradual settlements and movements in the subgrade without cracking. Since virtually all subgrades either settle (under loading) or rise (from soil expansion), flexibility is a desirable characteristic for all HMA pavements.

An open graded HMA with high binder content is generally more flexible than a dense graded, low binder content HMA. Sometimes the need for flexibility conflicts with stability requirements, so that trade offs have to be made.

Fatigue Resistance

Fatigue resistance is the pavement's resistance to repeated bending under wheel loads (traffic). Research shows that air voids (related to binder content) and binder viscosity have a significant effect on fatigue resistance. As the percentage of air voids in the pavement increases, either by design or lack of compaction, pavement fatigue life (the length of time during which an in-service pavement is adequately fatigue-resistant) is drastically shortened. Likewise, a pavement containing binder that has aged and hardened significantly has reduced resistance to fatigue.

The thickness and strength characteristics of the pavement and the supporting strength of the subgrade also have a great deal to do with determining pavement life and preventing load associated cracking. Thick, well supported pavements do not bend as much under loading as thin or poorly supported pavements do. Therefore, they have longer fatigue lives.

Figure 4-7 presents a list of causes and effects of poor fatigue resistance.

POOR FATIGUE RESISTANCE

Causes	Effects
Low asphalt binder content	Fatigue cracking
High design voids	Early aging of binder followed by fatigue cracking
Lack of compaction	Early aging of binder followed by fatigue cracking
Inadequate pavement thickness	Excessive bending followed by fatigue cracking

Figure 4-7. Causes and Effects of Poor Fatigue Resistance

SUPERPAVE MIX DESIGN METHOD

The Superpave mix design method is a **volumetric mix design** which includes an improved material selection process. An analysis of specimens and the maximum specific gravity sample are conducted to evaluate such properties as voids in mineral aggregate (VMA), voids filled with asphalt (VFA), air voids and dust/effective binder ratio. The designer uses this information to determine the parameters that need adjustment before fabricating additional specimens. This process is repeated several times until the designed aggregate structure and the binder content produce specimens with the desired volumetric properties. Using the information gained from this procedure, the designer then proceeds with preparing two specimens at four binder contents in preparation for determining the optimum binder content needed to produce the required four percent air voids at N_{des} gyrations.

Aggregates

The approach to the Superpave method of volumetric mix design begins with evaluating potential materials for use in the HMA mixture. The evaluation of aggregates is made for such properties as sand equivalency, fine and coarse aggregate angularity, and flat and elongated particles. By performing these tests on individual aggregates prior to developing trial blends, the designer develops a history of the material, and can make a determination of potential use of those materials in the design mixture.

Once the designer has selected the potential aggregates for use in the designed mixture, the aggregates are proportioned to comply with the composition limits specific to the nominal maximum particle size. If the designer has had no prior experience in working with Superpave mixtures, several trial blends may be necessary as a time saving design technique. The 0.45 power gradation chart is used to plot the combined gradation of the HMA. Figure 4-8 illustrates several important features for a 12.5 mm HMA that the aggregate gradation is required to meet. These are explained as follows:

Maximum Size: One sieve size larger than the nominal maximum size.

Nominal Maximum Size: One sieve size larger than the first sieve to retain more than 10 percent.

The **maximum density line** represents a gradation in which the aggregate particles fit together in their densest possible arrangement. This is a gradation to avoid because there would be very little aggregate space within which to develop sufficiently thick binder films for a durable HMA.

Control points are the specification ranges through which gradations must pass. They are placed on the nominal maximum size, an intermediate size (No. 8), and the dust size (No. 200).

The **restricted zone** is an area along the maximum density line between the intermediate size (either the No. 4 or No. 8 sieves) and the No. 50 sieve size. This zone forms a band through which gradations are not permitted to pass. Gradations that pass through the restricted zone indicate a mixture that has too much fine sand in relation to total sand. This gradation often results in tender mix behavior, which results in a mixture that is difficult to compact during construction and offers reduced resistance to rutting during its performance life.

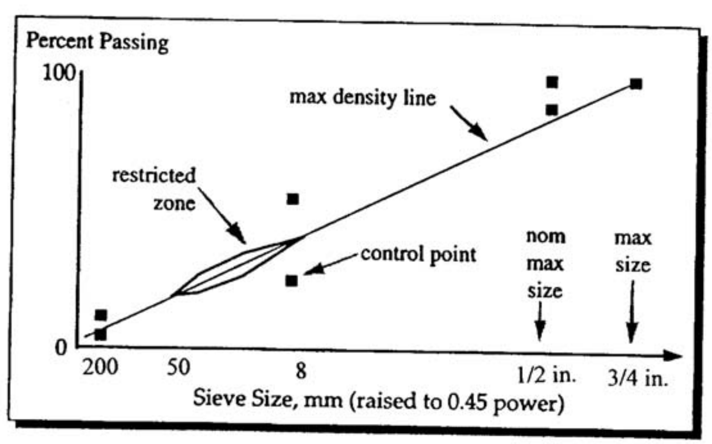

Figure 4-8. Superpave Gradation Limits 1/2 in. Mixture

Superpave Specimens

From the aggregate blend, the designer estimates the binder demand needed for the selected aggregate structure and proceeds with preparing a maximum specific gravity sample and a set of 150 mm specimens for compaction in the Superpave gyratory compactor. A new compactor was developed for the Superpave Mix Design to address more realistically the mix densities achieved under actual pavement climate and loading conditions. This device is capable of accommodating large aggregate, recognizing potential tender mix behavior and similar compaction problems, and is well suited for mixing plant quality control operations. The compactor is designated the Superpave Gyratory Compactor (SGC). Figure 4-9 illustrates a generic SGC and Figure 4-10 illustrates the SGC mold configuration and compaction parameters.

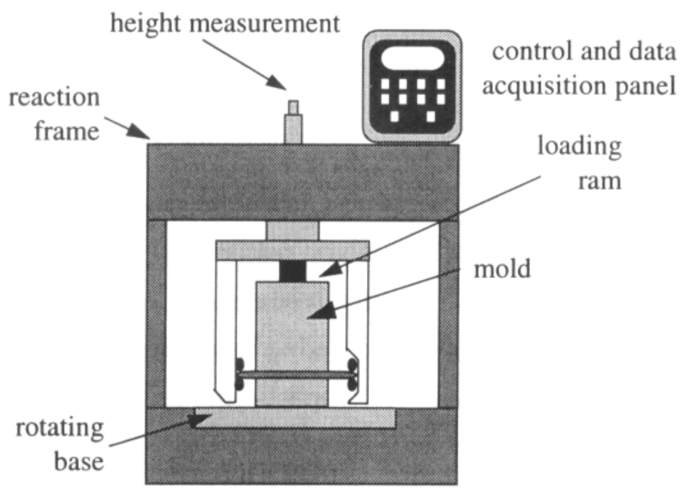

Figure 4-9. Superpave Gyratory Compactor

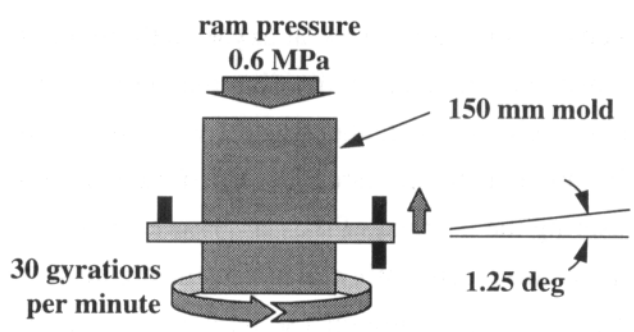

Figure 4-10. SGC Mold Configuration and Compaction Parameters

Specimens compacted with the Superpave gyratory compactor in the mix design are analyzed at a different number of gyrations depending on the traffic for the project and whether the mixture is a dense graded or open graded mixture. (Figure 4-11). The procedure used for preparing Superpave specimens is **AASHTO T 312**. Three gyration levels are of interest:

Ndes = design number of gyrations
Nini = initial number of gyrations
Nmax = maximum number of gyrations

GYRATORY COMPACTION EFFORT					
ESAL	Nini	Ndes	Nmax	Max. % Gmm @Nini	Max. % Gmm @Nmax
DENSE GRADED					
<300,000	6	50	75	91.5	98.0
300,000 to 3,000,000	7	75	115	90.5	98.0
3,000,000 to <10,000,000	8	100	160	89.0	98.0
10,000,000 to <30,000,000	8	100	160	89.0	98.0
>30,000,000	9	125	205	89.0	98.0
OPEN GRADED					
ALL ESAL	NA	20	NA	NA	NA

Figure 4-11. Superpave Gyratory Compactive Effort

The compactive efforts Nini and Nmax are used to evaluate the compatibility of the HMA, while Ndes is used to select the binder content. A maximum percentage of maximum theoretical density (Gmm) requirement at Nini insures an adequate aggregate structure in the HMA. A maximum percentage of maximum theoretical density (Gmm) requirement at Nmax insures that the HMA will not compact excessively under the anticipated traffic, and therefore produce permanent deformation or rutting.

Specimens in the mix design are compacted to Ndes at each increment of binder content to evaluate the required air voids and VMA. After a design binder content has been tentavely selected, two specimens at the design content are compacted to Nmax. Figure 4-11 lists the requirements at the optimum binder content for Maximum % Gmm at Nmax and Maximum % Gmm at Nini. The Maximum % Gmm at Nmax is determined by compacting the mix to Nmax, measuring the bulk specific gravity, and calculating the % Gmm using the Maximum Specific Gravity value at the optimum binder content. The Maximum % Gmm at the Nini is determined by estimating the Bulk Specific Gravity at Nini and using the Maximum Specific Gravity Value at the optimum binder content. The estimated value of the bulk specific gravity value at Nini is determined by knowing the weight of the mix, the fixed volume of the mold and the measured height at Nini. After compaction to Nmax, the measured Gmb at Nmax and the Gmm at optimum binder content are input into the computer program of the gyratory compactor so that the % Gmm at Nini can be calculated. An example of the compaction sheet, including the graph of Number of Gyrations versus **%** Gmm, is shown in Figure 4-12. The calculations that are made are as follows:

Bulk Specific Gravity (Corrected for Nini)

$$\text{Gmb (corr) @ Nini} = \text{Gmb (meas) @ Nmax} \times \frac{\text{height @ Nmax}}{\text{height @ Nini}}$$

Gmb = Bulk Specific Gravity of Mixture

% Maximum Specific Gravity (Corrected for Nini)

$$\text{\% Gmm (corr) @ Nini} = 100 \times \frac{\text{Gmb (corr) @ Nini}}{\text{Gmm (meas)}}$$

Gmm = Maximum Specific Gravity

% Gmm (corr) @ Nini = Maximum Specific Gravity @ Nini, Percent (Expressed as Decimal)

Gmm(meas) = 2.442 Gmb(meas) = 2.419

%AC = 4.6 Gsb = 2.606

	SPECIMEN 1		SPECIMEN 2		AVG.
GYRATIONS	HEIGHT, mm	%Gmm(corr)	HEIGHT, mm	%Gmm(corr)	%Gmm(corr)
5	136.4	82.9	136.5	82.8	82.9
8	132.9	85.1	133.1	84.9	85.0
10	131.1	86.3	131.4	86.0	86.2
20	126.1	89.7	126.4	89.4	89.6
30	123.2	91.8	123.5	91.5	91.7
40	121.3	93.3	121.7	92.9	93.1
50	119.9	94.3	120.3	94.0	94.2
60	118.8	95.2	119.2	94.8	95.0
70	117.9	95.9	118.3	95.5	95.7
80	117.2	96.5	117.5	96.2	96.4
90	116.5	97.1	116.9	96.7	96.9
96	116.2	97.4	116.6	96.9	97.1
130	114.8	98.5	115.1	98.2	98.4
152	114.2	99.1	114.1	99.1	99.1

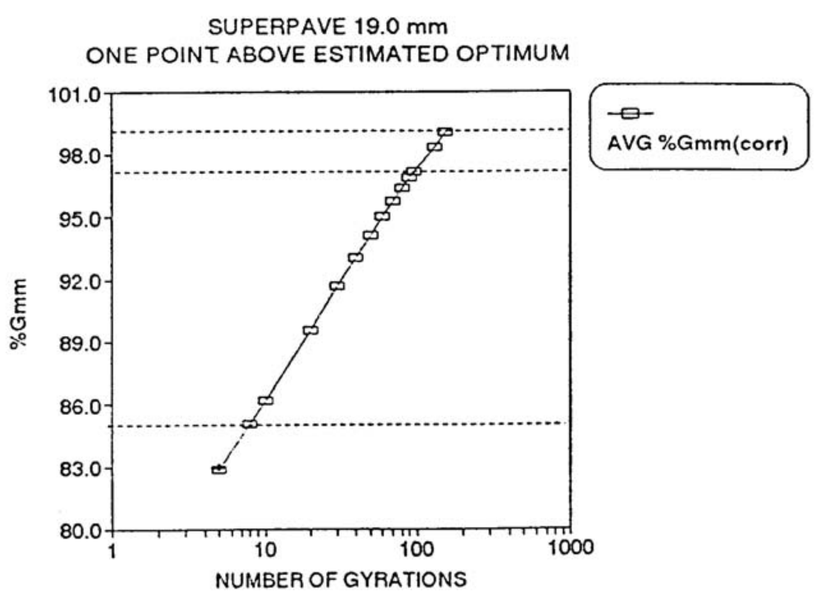

Figure 4-12. Gyratory Densification Data

Maximum Specific Gravity

To determine the maximum specific gravity when weighing in air, the dry loose mixture is weighed, placed in a tared vacuum container, and covered with water. A partial vacuum of 25.5 to 30 mm Hg is applied to the container for 15 ± 2 minutes. At the end of the vacuum period the vacuum is gradually released, and the container is filled with water at 77 ± 1.8°F and weighed (**AASHTO T 209**). Calculations are as follows:

$$\text{Maximum Specific Gravity (Gmm)} = \frac{A}{A + D - E}$$

where:

A = weight of oven dry sample in air, g
D = weight of container filled with water at 77°F, g
E = weight of container filled with sample and water at 77°F, g

To determine the maximum specific gravity when weighing in water, follow the procedure for weighing in air until the vacuum period is complete and the vacuum released. The container and contents are then suspended in a water bath and the weight determined after 10 ± 1 min immersion. The container is immediately emptied and weighed by itself totally submerged in the water bath. Calculations are as follows:

$$\text{Maximum Specific Gravity (Cmm)} = \frac{A}{A - (C - B)}$$

where:

A = weight of oven dry sample in air, g
B = weight of container in water, g
C = weight of container and sample in water, g

A supplemental procedure for mixtures containing porous aggregate is recommended when the HMA contains an individual aggregate with a water absorption of 1.5 percent or greater. The procedure requires the sample to be spread before an electric fan to remove surface moisture. The sample is weighed at 15-minute intervals until the loss in mass is less than 0.05 percent for this interval. This weight is designated the surface dry weight. Calculations are as follows:

$$\text{Maximum Specific Gravity (Gmm)} = \frac{A}{A_1 - (C-B)}$$

where:

A = weight of oven dry sample in air, g
A_1 = weight of surface dry sample, g
C = weight of container in water , g
E = weight of container and sample in water , g

Bulk Specific Gravity

To determine the bulk specific gravity, the compacted specimens are extruded from the mold, cooled to room temperature, and the dry weight recorded. (A cooling period of 5 to 10 minutes in front of a fan may be necessary before extruding some specimens to insure the specimens are not damaged). Each specimen is then immersed in water at 77 ± 1.8°F for three to five minutes, and the immersed weight is recorded. The specimen is removed from the water, surface dried by blotting with a damp cloth, and the surface dry weight recorded in air (**AASHTO T 166**). The bulk specific gravity of the specimen is calculated as follows:

$$\text{Bulk Specific Gravity (Gmb)} = \frac{A}{B\text{-}C}$$

where:

A = weight of specimen in air, g
B = weight of surface-dry specimen in air, g
C = weight of specimen in water, g

The bulk specific gravity may be converted to density by multiplying by 62.416 lb/ft^3.

Upon completion of the test, the percent water absorbed by the specimen is calculated as follows:

$$\text{Percent Water Absorbed by Volume} = \frac{B - A}{B - C} \times 100$$

If the percent water absorbed by the specimen exceeds 2 percent, the procedure using paraffin-coated specimens (**AASHTO T 275**) is used. This procedure requires that the specimen be coated with paraffin prior to weighing in water. The bulk specific gravity of the specimens is calculated as follows:

$$\text{Bulk Specific Gravity (Gmb)} = \frac{A}{D - E - \left(\frac{D - A}{F}\right)}$$

where:

A = weight of dry specimen in air, g
D = weight of dry specimen plus paraffin coating in air, g
E = weight of dry specimen plus paraffin in water, g
F = specific gravity of the paraffin at 77 ± 1.8°F (use 0.9)

Dust Proportion

The dust proportion is computed as the ratio of the percentage by mass of aggregate finer than the No. 200 sieve to the calculated effective binder content expressed as a percent of total mix. The dust proportion is calculated as follows:

$$\text{Dust Proportion} = \frac{P\,200}{Pbe}$$

where:

P 200 = aggregate content passing the No. 200 sieve, percent by weight of aggregate

Pbe = effective binder content, percent by total weight of mixture

The absorbed asphalt (Pba) is first calculated and then the effective binder content is determined.

$$\text{Absorbed Asphalt (Pba)} = 100 \times \frac{Gse - Gsb}{Gsb\ Gse} \times Gb$$

where:

Gse = effective specific gravity of aggregate

Gsb = bulk specific gravity of aggregate

Gb = specific gravity of binder

$$\text{Effective Binder Content (Pbe)} = Pb - \frac{Pba}{100} \times Ps$$

where:

Pb = binder content, percent by total weight of mixture

Ps = aggregate content, percent by total weight of mixture

Air Voids

Once the bulk specific gravity and maximum specific gravity of the HMA have been determined, the air voids (Va) are calculated as follows:

$$\text{Air Voids (Va)} = 100 \times \frac{Gmm - Gmb}{Gmm}$$

where:

Gmm = Maximum Specific Gravity of HMA

Gmb = Bulk Specific Gravity of HMA

Voids in the Mineral Aggregate

The voids in the mineral aggregate (VMA) is determined on the basis of bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted mix. Therefore, VMA is calculated by subtracting the volume of the aggregate determined by its bulk specific gravity from the bulk volume of the compacted HMA and is calculated as follows:

$$\text{Voids in the Mineral Aggregate (VMA)} = 100 - \frac{Gmb\ Ps}{Gsb}$$

where:

Gmb = Bulk Specific Gravity of HMA
Gsb = Bulk Specific Gravity of aggregate
(Obtained from design mix formula)
Ps = Aggregate, percent by total weight of HMA

The percent of aggregate by total weight of HMA (Ps) is determined by subtracting the actual binder content by total weight of HMA (Pb) supplied on the design mix formula from 100.

$$Ps = 100 - Pb$$

Voids Filled with Asphalt

The voids filled with asphalt (VFA) is the percentage of the VMA that contains binder. The VFA is calculated as follows:

$$\text{Voids Filled with Asphalt (VFA)} = \frac{(VMA - Va)}{VMA} \times 100$$

Recycled Materials

Recycled materials may be used in Superpave mixtures provided that the recycled mixture adheres to the same criteria as a mixture without any recycled materials. Recycled materials are not permitted for mainline surface mixtures using QC/QA HMA or open graded mixtures. Recycled materials may consist of reclaimed asphalt pavement (RAP), or asphalt roofing shingles (ARS), or a blend of both. RAP is the product resulting from the cold milling or crushing of an existing HMA pavement. ARS is waste from a shingle manufacturing facility. No tear-off materials from roofs are allowed to be used as ARS.

When only RAP is used in the mixture, the RAP may not exceed 25.0 percent by weight of the total mixture. When only ARS is used in the mixture, the ARS may not exceed 5.0 percent by weight of the total mixture. For substitution or use, 1.0 percent of ARS is considered equal to 5.0 percent RAP.

For QC/QA HMA, when 15.0 percent or less of RAP is used, the grade of binder for the mixture remains the same. However, when more than 15.0 percent and up to 25.0 percent RAP is used, the binder grade is reduced by one temperature classification, 6°C, for both the upper and lower temperature classifications. The following table illustrates this requirement:

<u>QC/QA HMA</u>

Specified PG Grade	≤15.0% RAP	>15.0 to 25.0% RAP
64-22	64-22	58-28
70-22	70-22	64-28
76-22	76-22	70-28

For HMA mixtures, when 15.0 percent or less of RAP is used, the grade of binder for the mixture remains the same. However, when more than 15.0 percent and up to 25.0 percent RAP is used, the binder grade is reduced by one temperature classification, 6°C, for the upper temperature classification and -28°C is used for the lower temperature classification. The following table illustrates this requirement:

<u>HMA</u>

Specified PG Grade	≤15.0% RAP	>15.0 to 25.0% RAP
64-22	64-22	58-28
70-22	70-22	64-28

Moisture Susceptibility

The final process involved in the volumetric mix design is to check the moisture susceptibility of the HMA. The procedure used is **AASHTO T 283**, except that the loose mixture curing is replaced by short term aging for 2 h in accordance with **AASHTO R 30**. Regardless of the mixture designation, all Superpave mixtures are required to meet a minimum tensile strength ratio (TSR) of 80 percent.

Example Calculations

A sample of the aggregate and compacted HMA are known to have the following properties. Determine the density, air voids, VMA, VFA, and Dust Proportion.

Effective Specific Gravity of Aggregate (Gse) = 2.726
Specific Gravity of Binder (Gb) = 1.030
Bulk Specific Gravity of Mix (Gmb) = 2.360
Bulk Specific Gravity of Aggregate (Gsb) = 2.715
Maximum Specific Gravity of Mix (Gmm) = 2.520
Binder Content (Pb) = 5.0 percent of weight of total mix
Aggregate Passing No. 200 (P 200) = 5.3

Density

$$D = Gmb \times 62.416 \text{ lb/ft}^3$$
$$= 2.360 \times 62.416$$
$$= 147.3 \text{ lb/ft}^3$$

Air Voids

$$Va = 100 \times \frac{Gmm - Gmb}{Gmm}$$

$$= 100 \times \frac{2.520 - 2.360}{2.520}$$

$$= 100 \times .063$$
$$= 6.3\%$$

VMA

$$Ps = 100 - Pb$$
$$= 100 - 5.0$$
$$= 95.0$$
$$VMA = 100 - \frac{Gmb\ Ps}{Gsb}$$

$$= 100 - \frac{2.360\ (95.0)}{2.715}$$

$$= 100 - 82.6$$
$$= 17.4\%$$

VFA

$$VFA = \frac{VMA - Va}{VMA} \times 100$$

$$= \frac{17.4 - 6.3}{17.4} \times 100$$

$$= 63.8\%$$

Dust Proportion

$$Pba = 100 \times \frac{2.726 - 2.715}{2.715 \times 2.726} \times 1.030$$

$$= 100 \times \frac{.011}{7.401} \times 1.030$$

$$= 0.15$$

$$Ps = 100 - 5.0 = 95.0$$

$$Pbe = 5.0 - \frac{0.15}{100} \times 95.0$$

$$= 5.0 - 0.1$$

$$= 4.9$$

$$\text{Dust Proportion} = \frac{P\ 200}{Pbe} = \frac{5.3}{4.9} = 1.1$$